Analysis of Electromagnetic Behavior of Permanent Magnetized Electrical Machines in Fault Modes

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Motivation for the project

- Increased usage of Permanent Magnet (PM) machines in the marine industry.
- 30-40% of faults in electrical machines are related to electromechanical faults – Stator winding faults [1]
- Stator faults – Insulation failures expand very quickly and may lead to fire on marine vessels
- This leads to loss of propulsion on marine vessels or in worst cases fires on board.

Figure1. Stator insulation failures [2]

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On shaft hybrid propulsion drive train

DNV GL requirements

During stator faults - make machine electrically dead without stopping propulsion for two long in order to

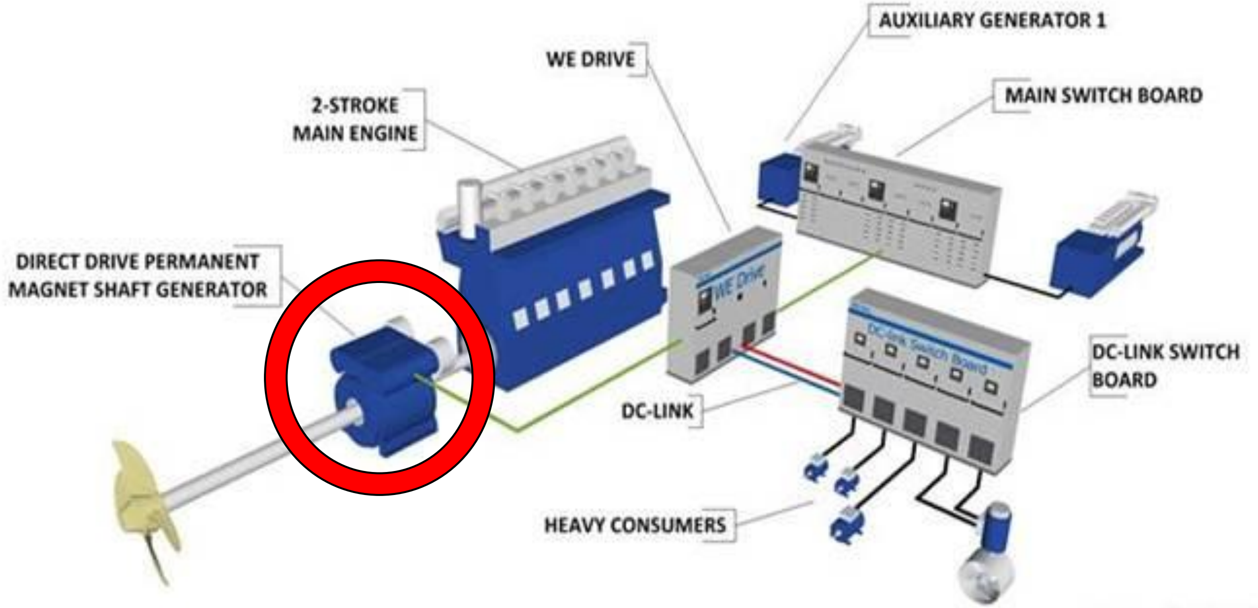
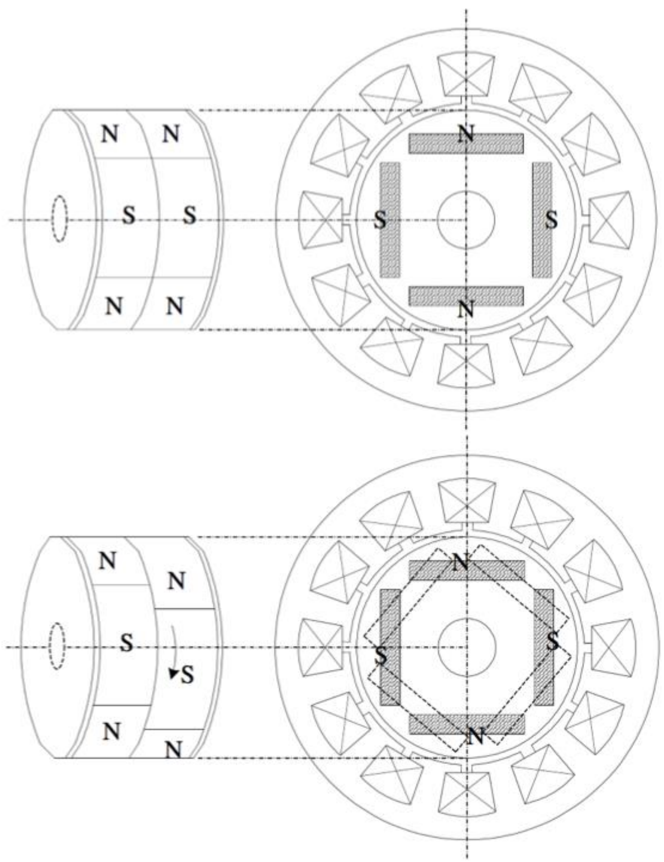


Figure2. On shaft generator for hybrid propulsion drive train

Dual Rotor Permanent Magnet Synchronous Machine (DR-PMSM)



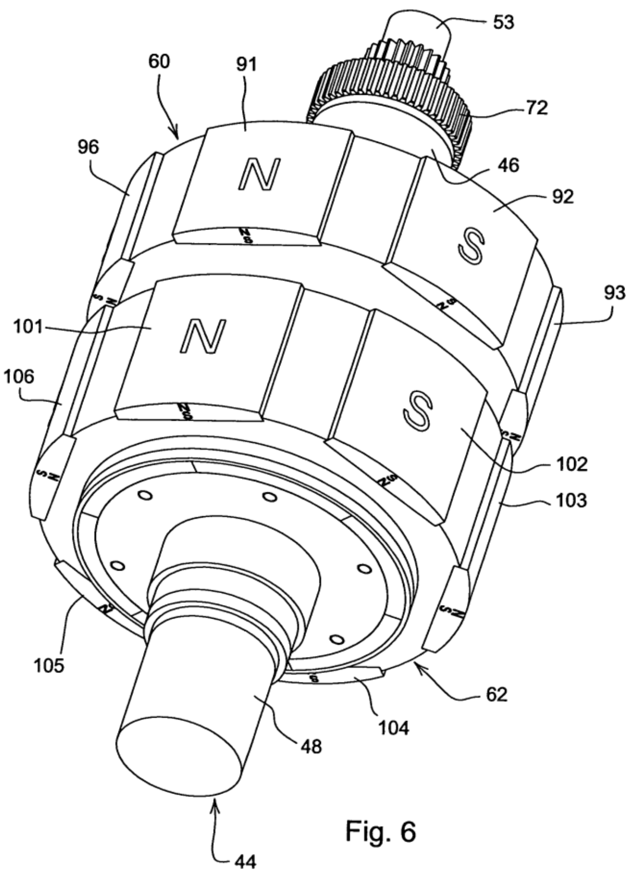


Fig. 6

Figure3. Construction of Dual Rotor PMSM [3]

3D FEM in COMSOL Multiphysics

WHY 3D modeling?

- Laminations in the stator required an-isotropic materials
- To study complex effects in DR-PMSM such as
  - eddy currents
  - non-linear characteristics of the machine
  - flux densities
  - Forces and torques

3D FEM in COMSOL Multiphysics

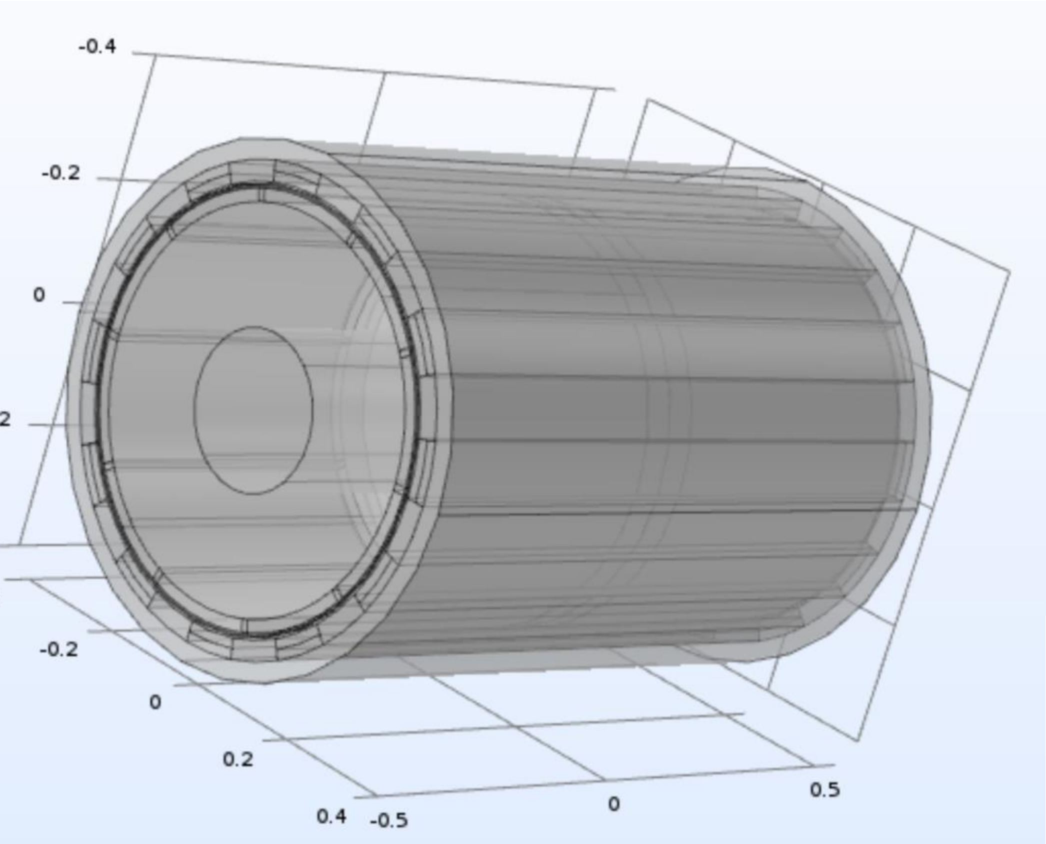
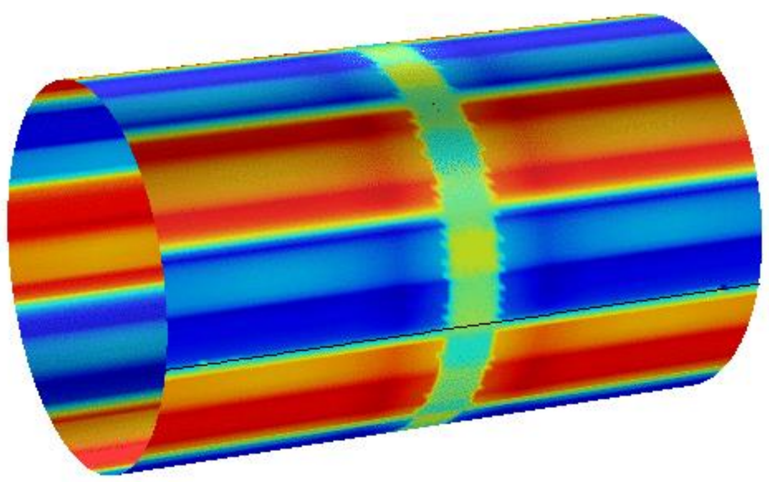


Figure4. 3D model of Dual Rotor PMSM [3]

Machine Parameters		
Parameter	Unit	Value
Machine Diameter	mm	800
Machine active length	mm	1000
Machine length	mm	1100
Rotor radius	mm	306
Airgap length	mm	10
Rotational Speed	rpm	115
Rated current	A	250
Poles	-	10
Stator slots	-	12
Winding layout	-	Double layer



Assumptions for 3D FEM

1. The material used in the machine model are linear, so that computational time can be reduced
2. The resistance of the coils has not been modeled
3. There are eddy current losses considered in the machine stator and for that laminations are modeled as permittivity and conductivity tensor
4. There are no eddy current losses considered in the rotor yoke and magnets.
5. The losses in the machine have not been considered.

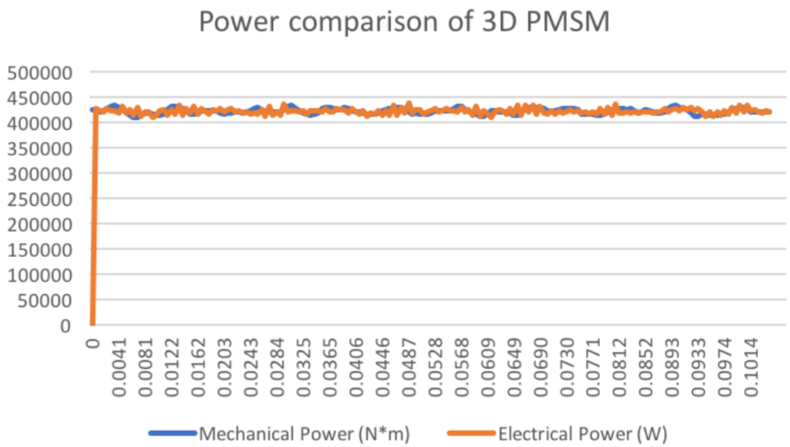
Computational Results

1. **Validity of the machine**
2. **Induced Voltages in the coil**
3. Forces acting on the rotor
4. **Flux in the stator**

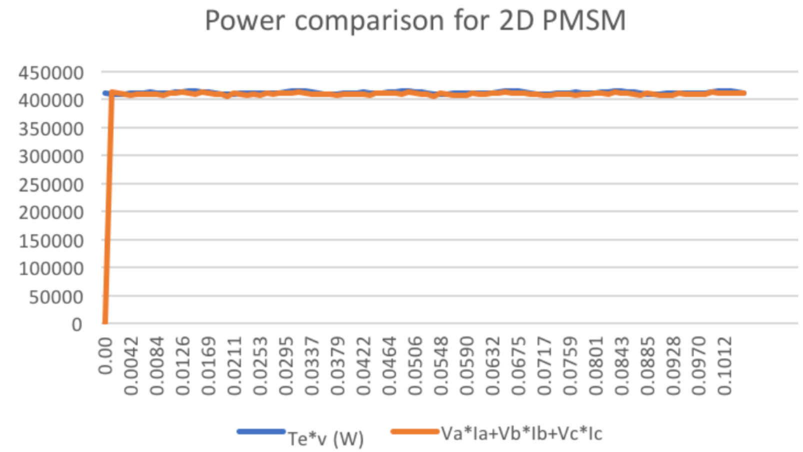
1. Validity of the machine

- Power Balance in DR PMSM and Conventional PMSM

$$T_e\omega = V_aI_a + V_bI_b + V_bI_b$$



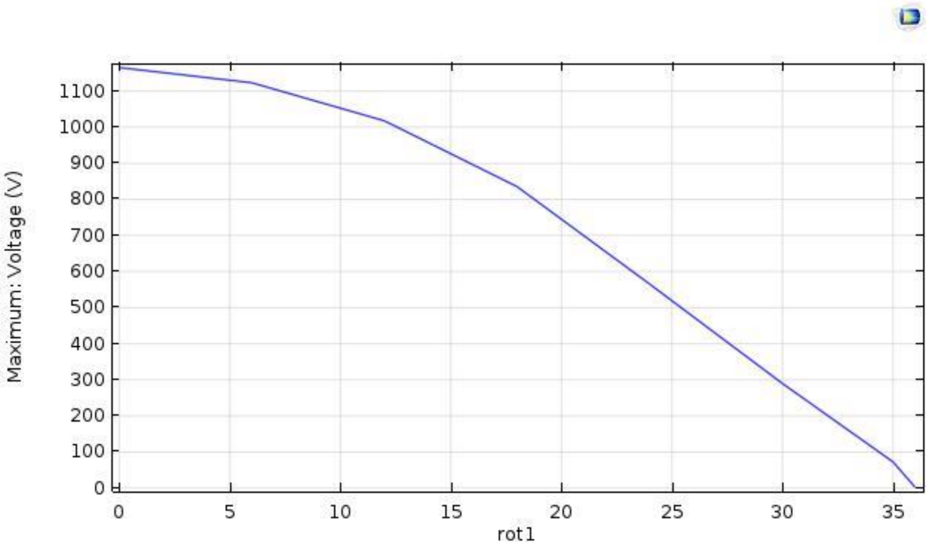
(a) DR-PMSM



(b) Conventional PMSM

Figure4. Mechanical and electrical power balance

2. Induced Voltages in the Coil



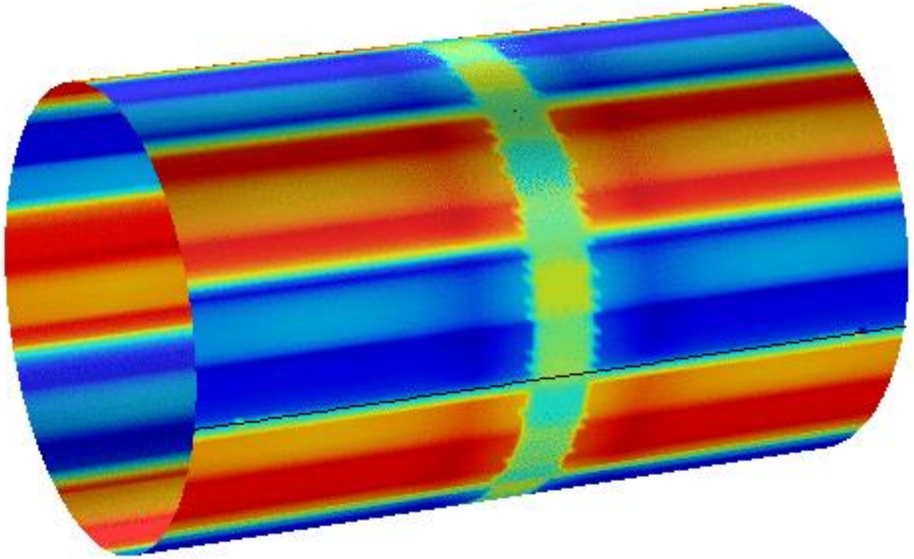
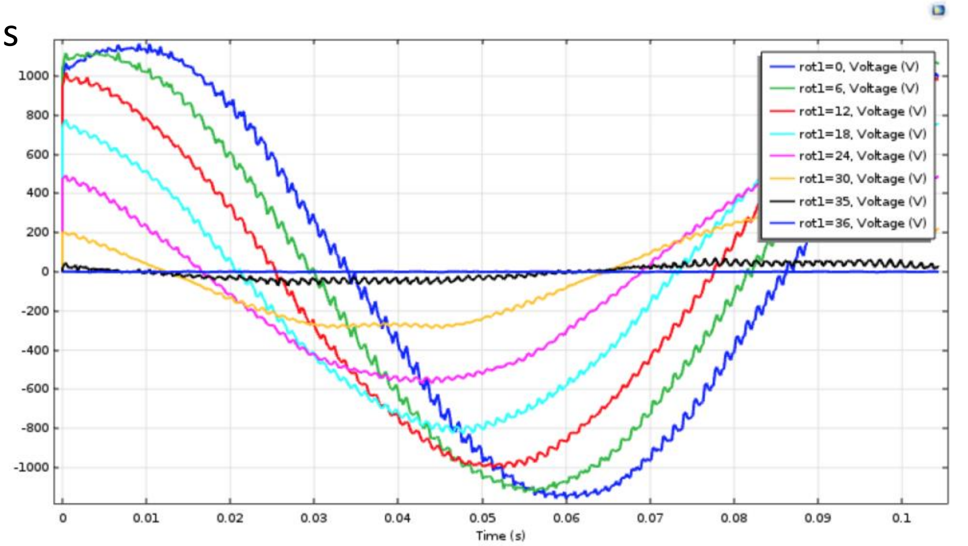


Figure5. Voltages in Phase A at various rotor positions



- Induced emf goes to zero due to re-alignment of magnets (flux weakening).

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4. Flux in the stator

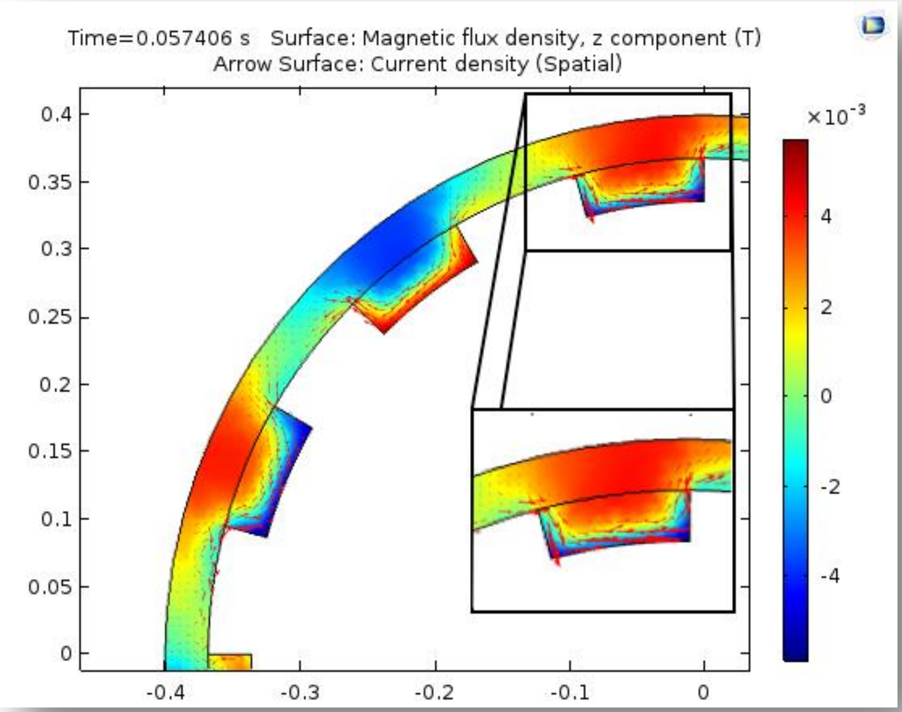
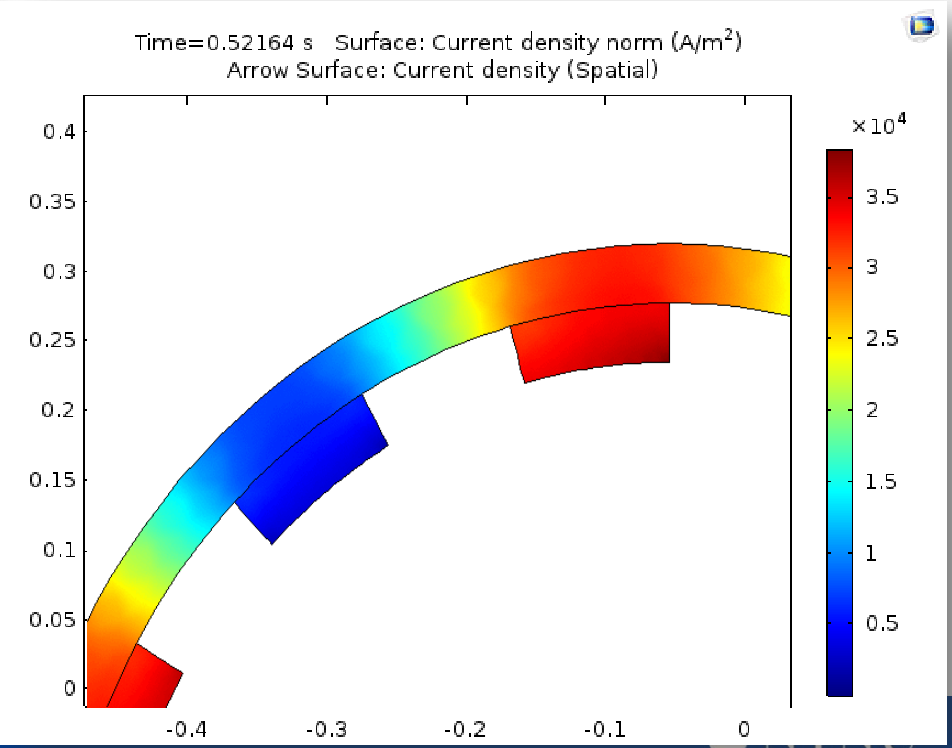


Figure6. Axial flux in the middle part of the stator

- Eddy current phenomenon can be seen clearly

- The maximum magnitude of the current is around 40 A/mm^2 which is just concentrated on the edges of the stator teeth.



Conclusions

1. The efficiency of DR-PMSM is similar to a conventional PMSM.

2. Induced voltages can be reduced to zero by the flux weakening mechanism in DR-PMSM.

3. The forces on the rotors due to the shifting mechanism can be minimized by reducing cogging in the machine.

4. Axial flux components in the machine induce certain hot spots in the middle part of the stator (between the gap of the two rotors), which should be further studied.

Questions

References:

[1] Z. Daneshi-Far, G. A. Capolino, and H. Henao, “Review of failures and condition monitoring in wind turbine generators,” in *The XIX International Conference on Electrical Machines - ICEM 2010*, 2010, pp. 1–6.

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[3] Alewine K, Chen W. A review of electrical winding failures in wind turbine generators. IEEE Electrical Insulation Magazine. 2012 Jul;28(4).